4D-Var data assimilation of atmospheric CO_2 from infrared satellite sounders

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Thanks to: Soumia Serrar, Yogesh Tiwari, Frédéric Chevallier and many others.

Outline

- COCO project – 1st attempt with a relatively simple data assimilation system
- GEMS project – towards a full 4-dimensional greenhouse gas data assimilation system
- Outlook & Conclusions

COCO

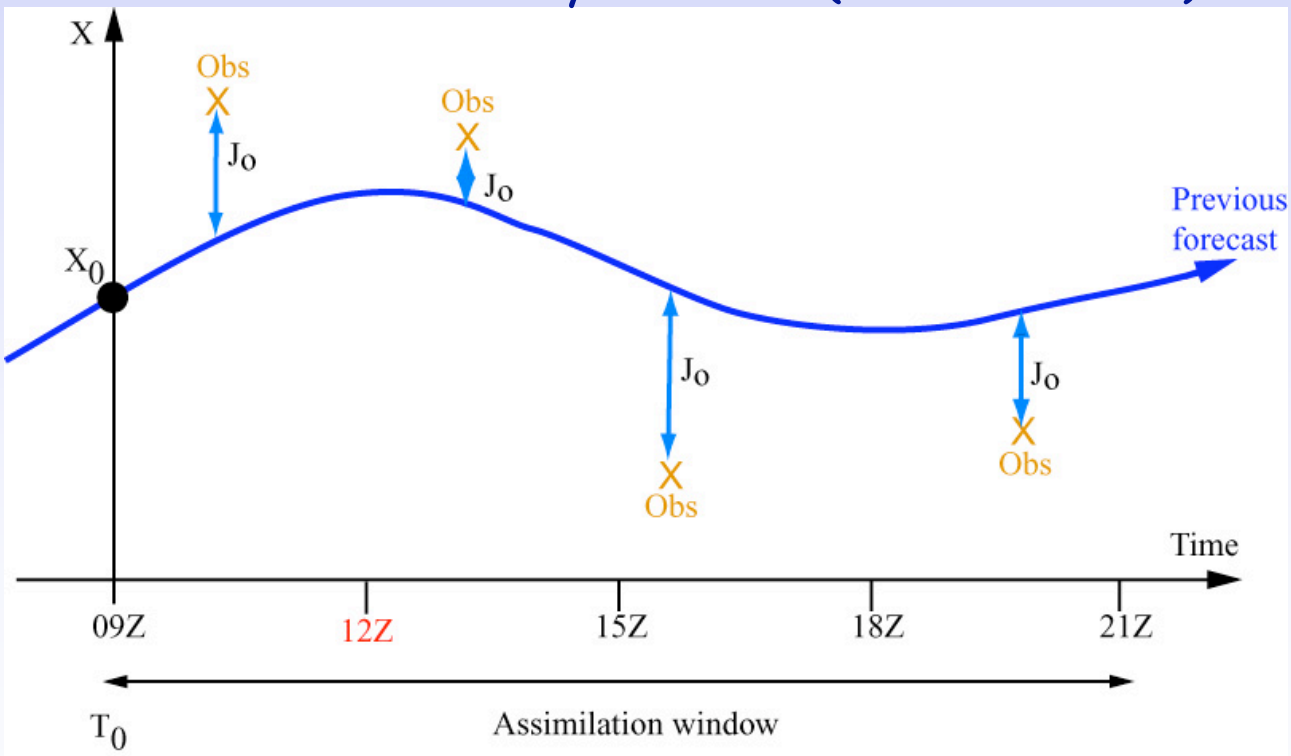
COCO (Measuring CO_2 from space exploiting planned missions 2001 - 2004) was an European Union funded Integrated Project (IP) within the Fifth Framework Programme.

The purpose of the COCO project was to take advantage of already planned satellite missions to develop, evaluate and apply methods for the estimation of CO_2 column inventories from space and subsequently to estimate CO_2 emissions and CO_2 surface exchange fluxes.

4D-Var Data Assimilation

4-dimensional variational data assimilation is in principle a least-squares fit in 4 dimensions between the predicted state of the atmosphere and the observations.

The adjustment to the predicted state is made at time T_o, which ensures that the analysis state (4-dimensional) is a model trajectory.



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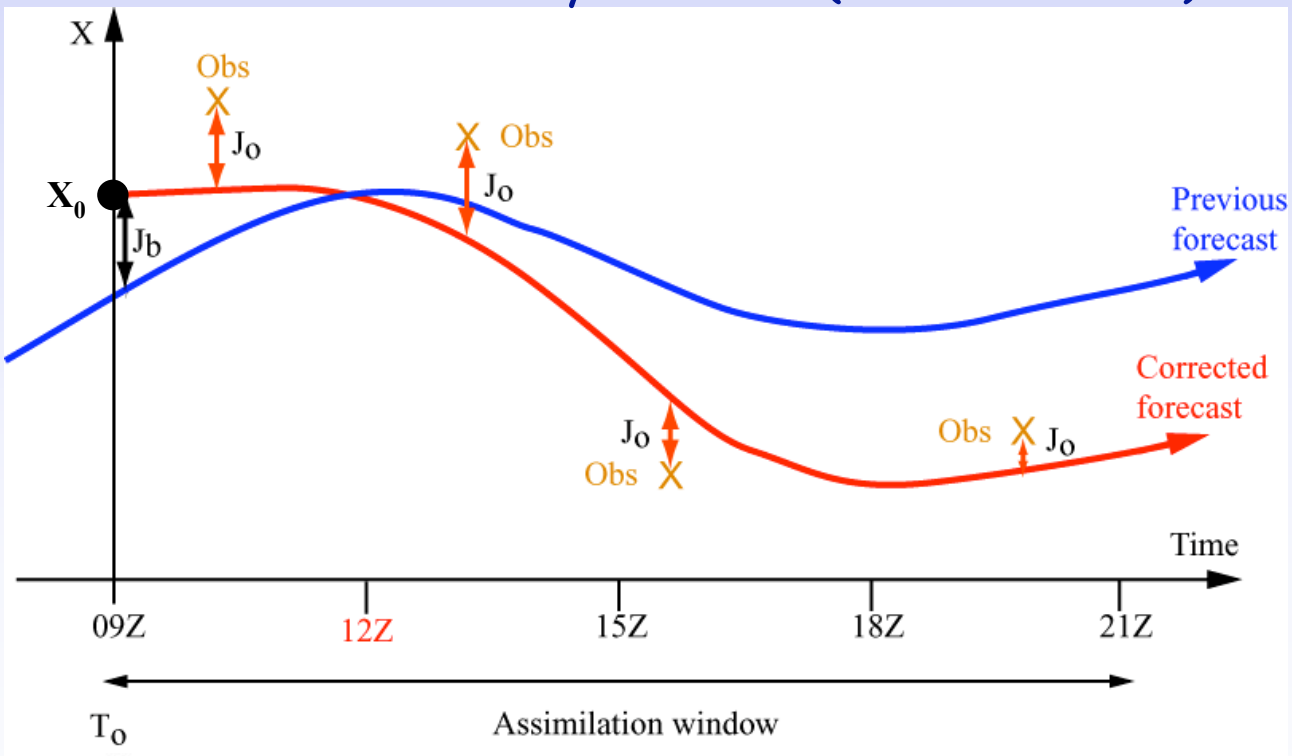

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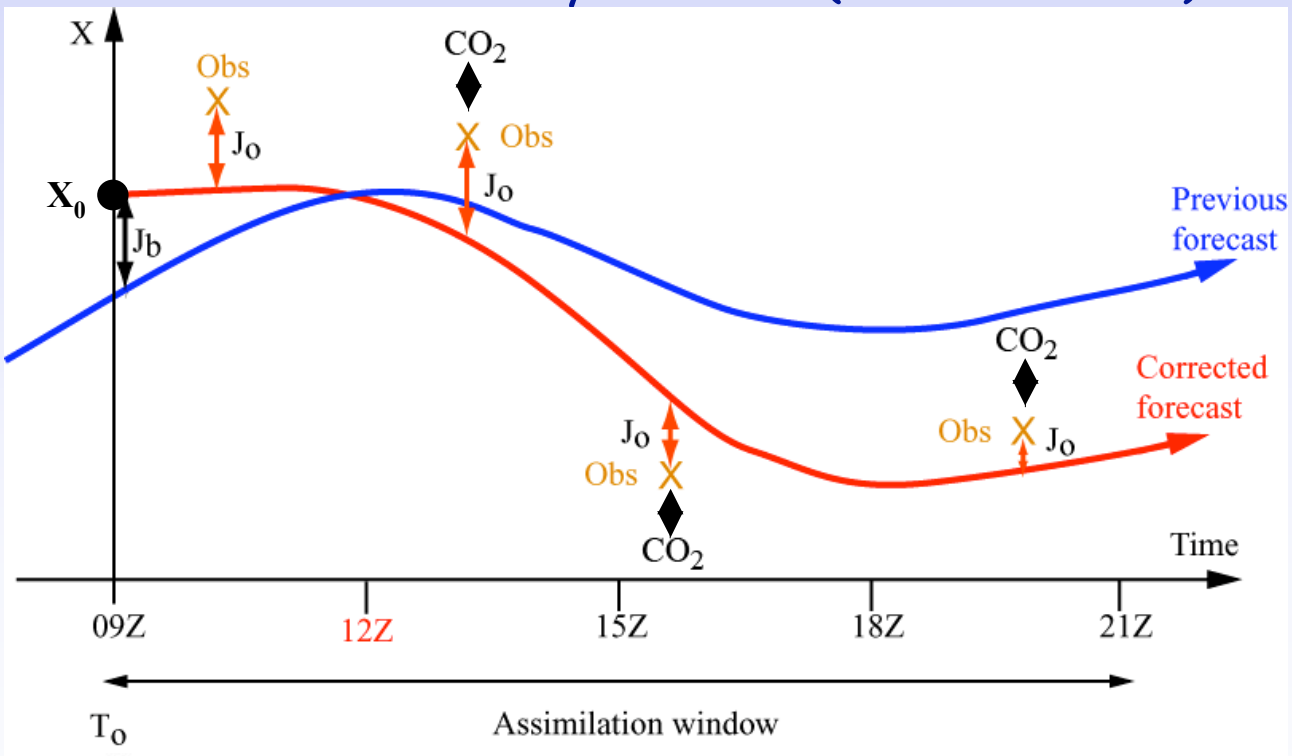
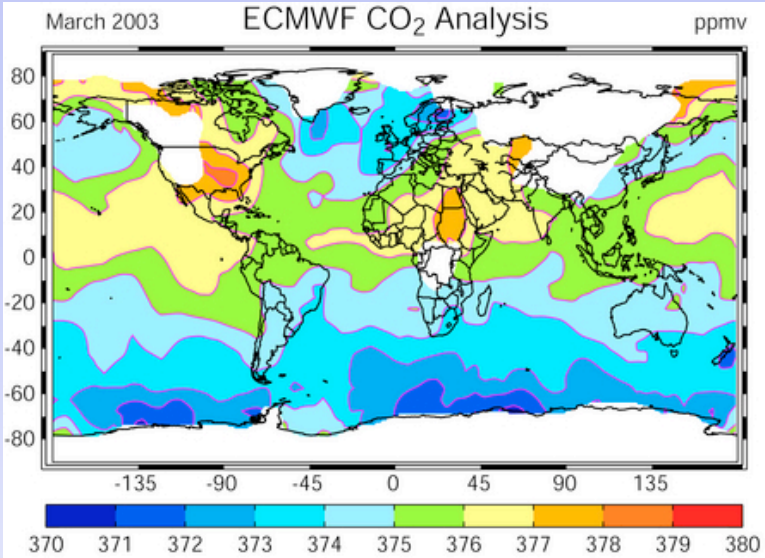
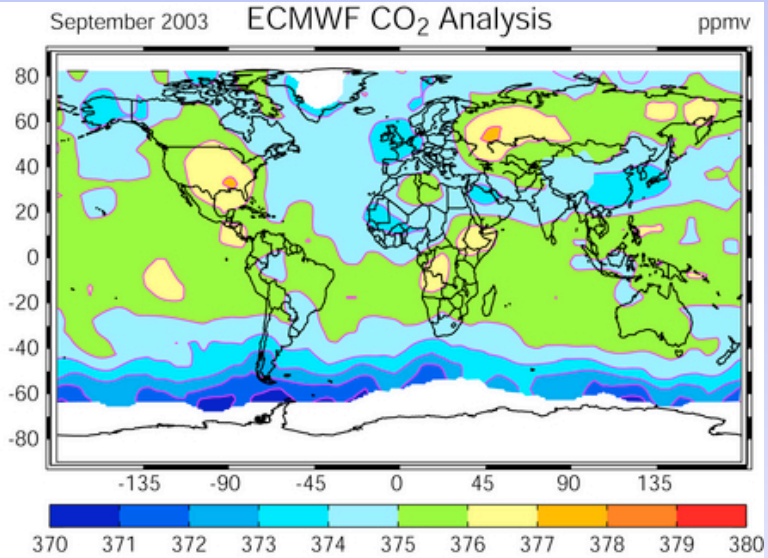


CO_2 is added to the state vector as a tropospheric column amount for each AIRS observation.

CO_2 column estimates

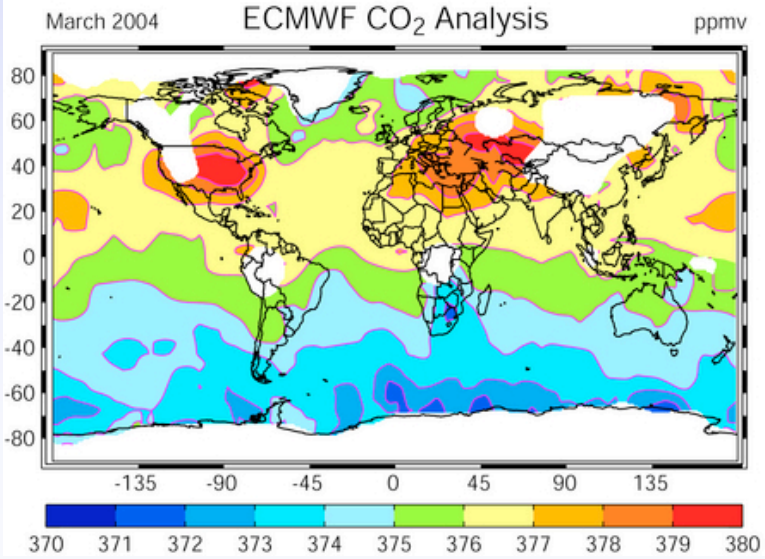
Mar 2003

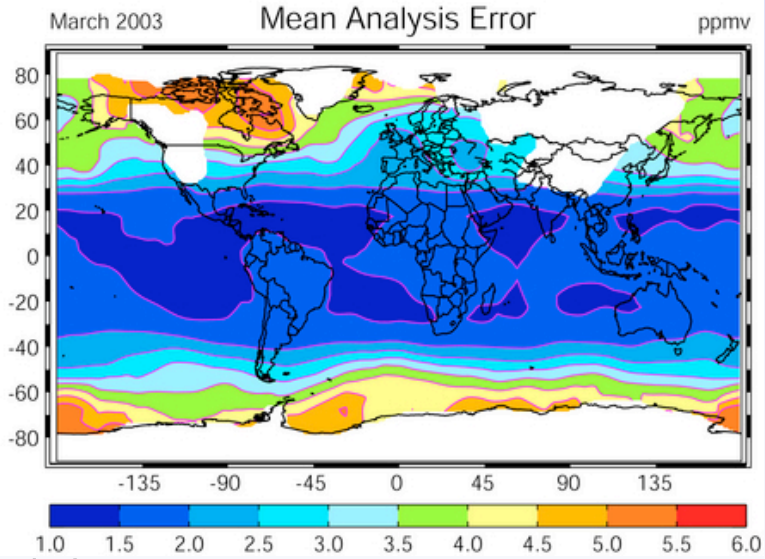




Sep 2003

Mar 2004

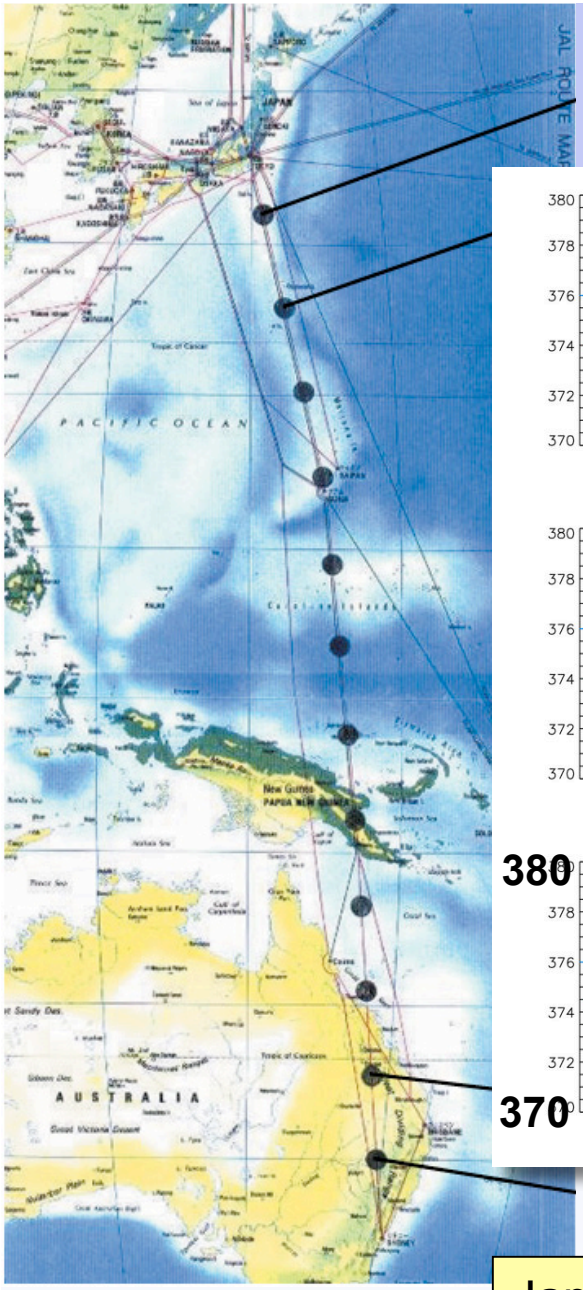


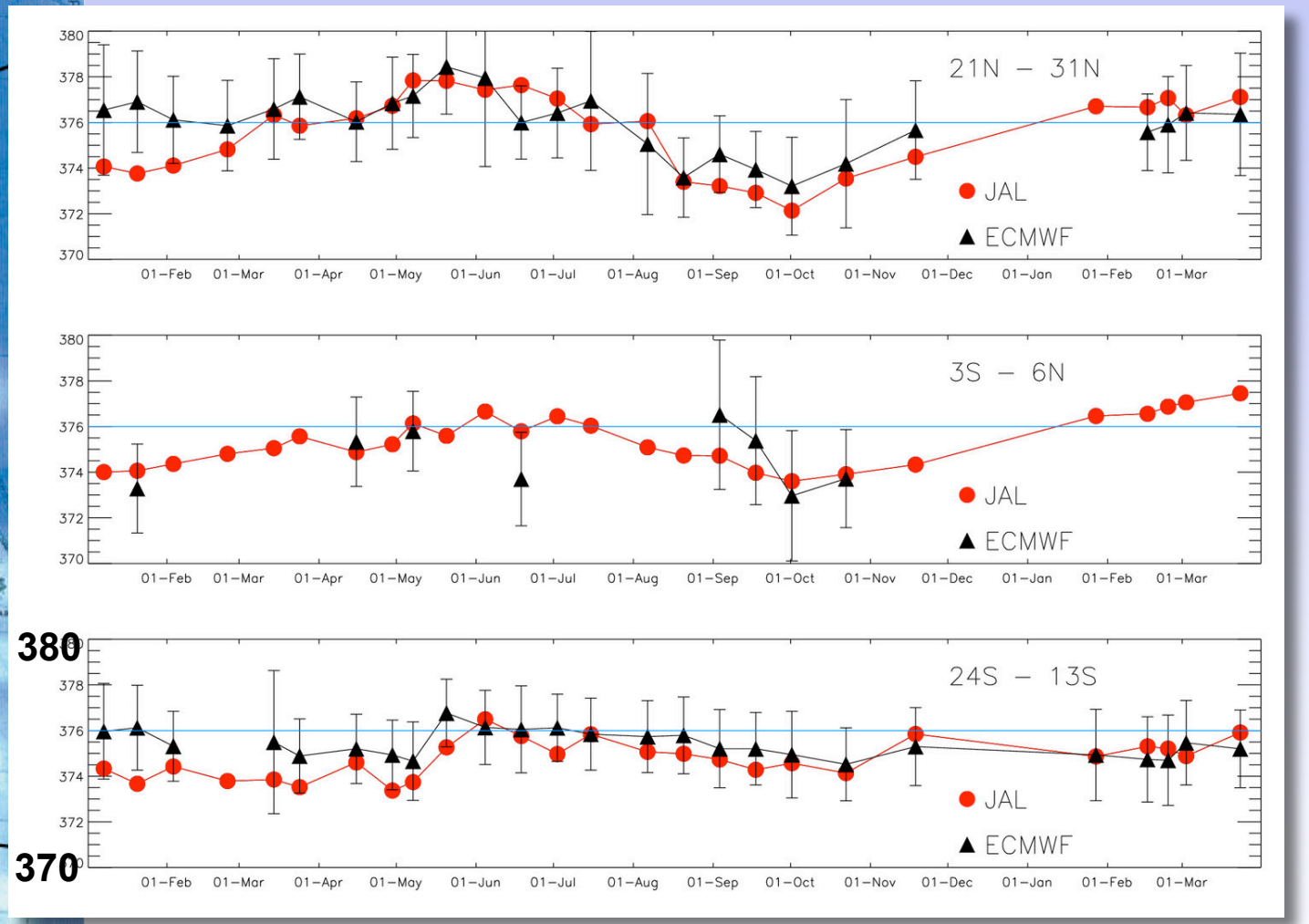


Mar 2003

370 380 1.0 6.0

Comparison with in-situ observations





Japanese flight data kindly provided by H. Matsueda, MRI/JMA

Comparisons with models

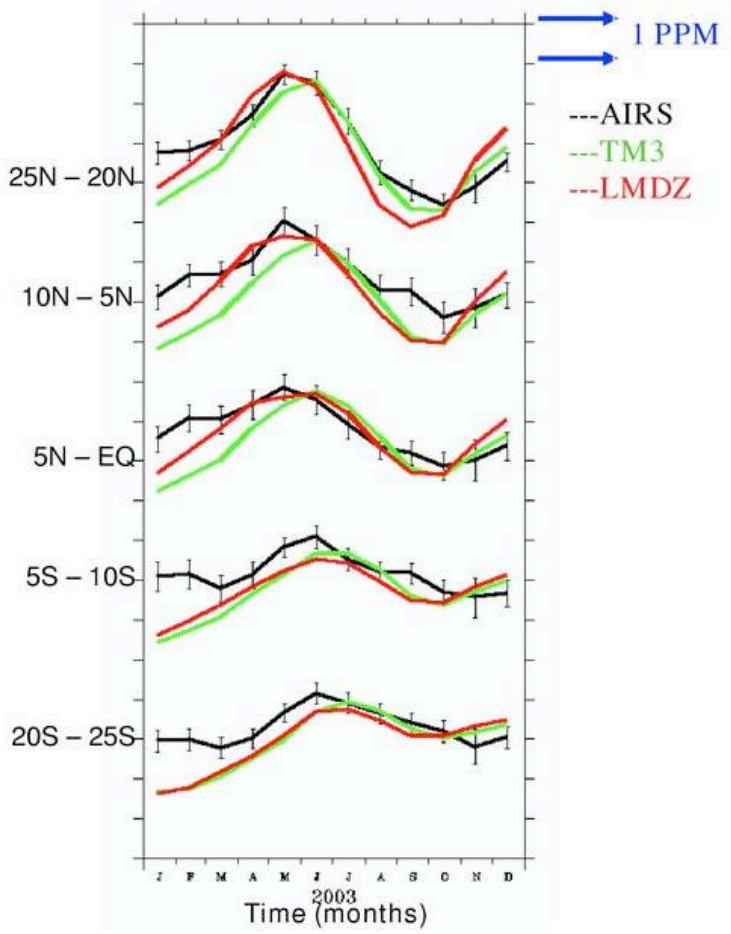


Figure7 : Monthly mean CO_2 (ppm) averaged zonally and over 5^0 latitudinal bands as retrieved by AIRS and simulated by TM3 and LMDZ.

Comparisons with models

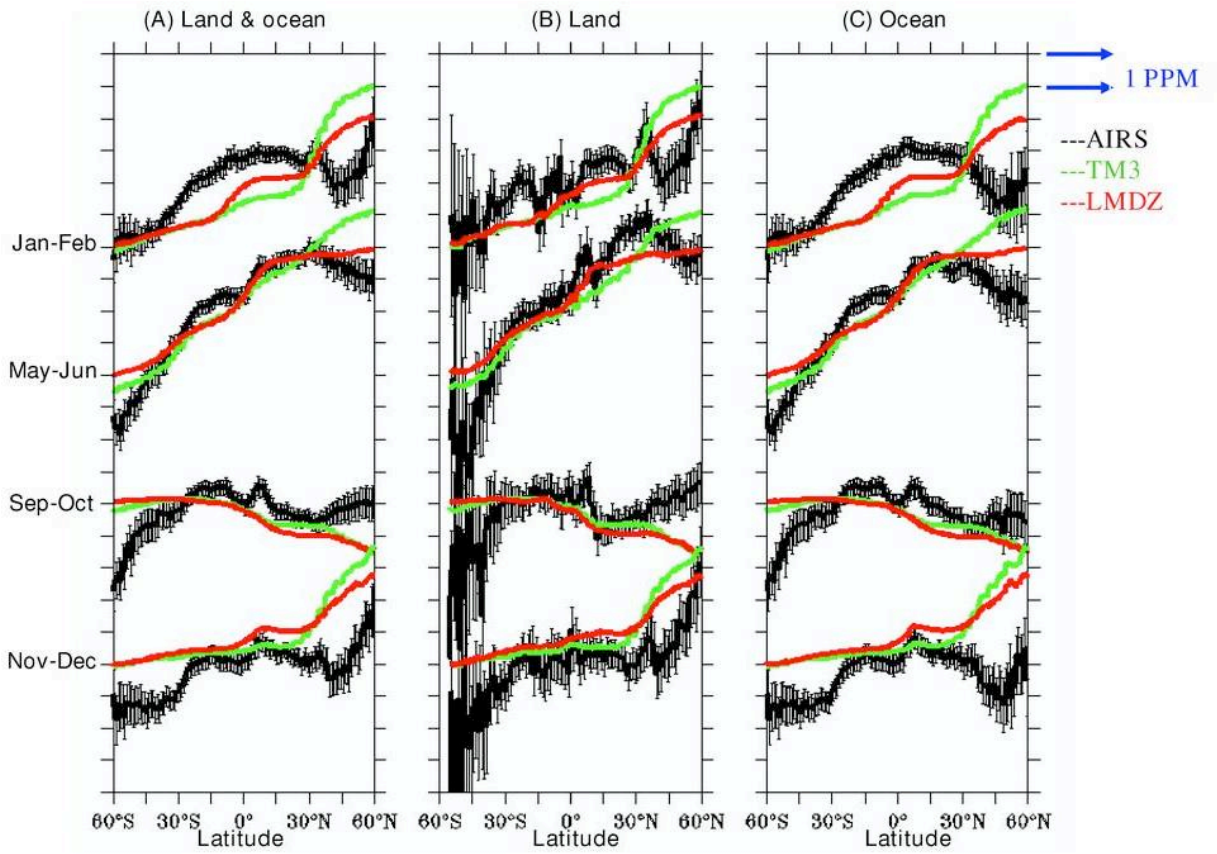


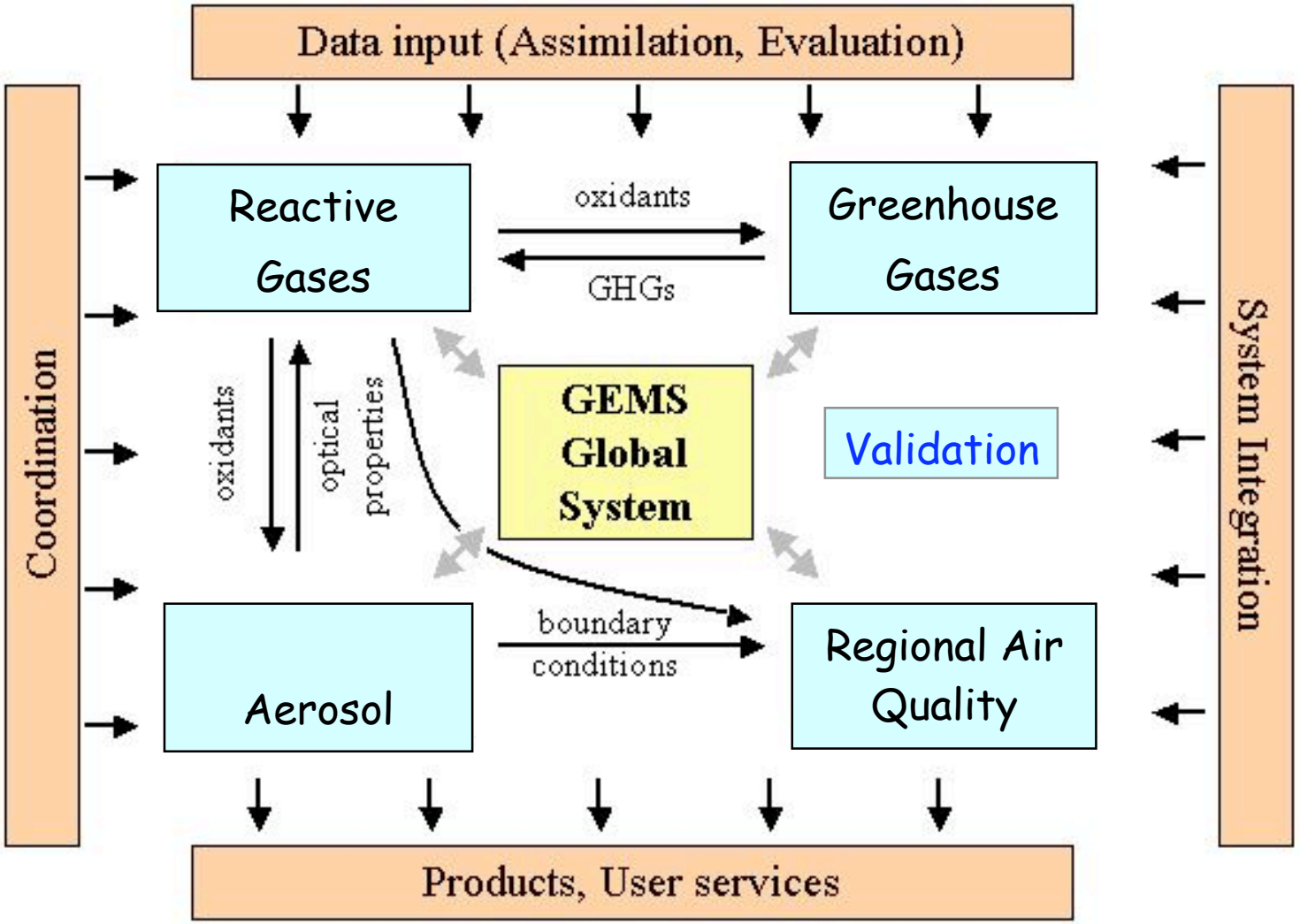
Figure 9 : Zonal mean latitudinal variation of CO_2 (ppm) averaged over two months period. (A) over land and ocean , (B) only over land, (C) only over oceans.

GEMS

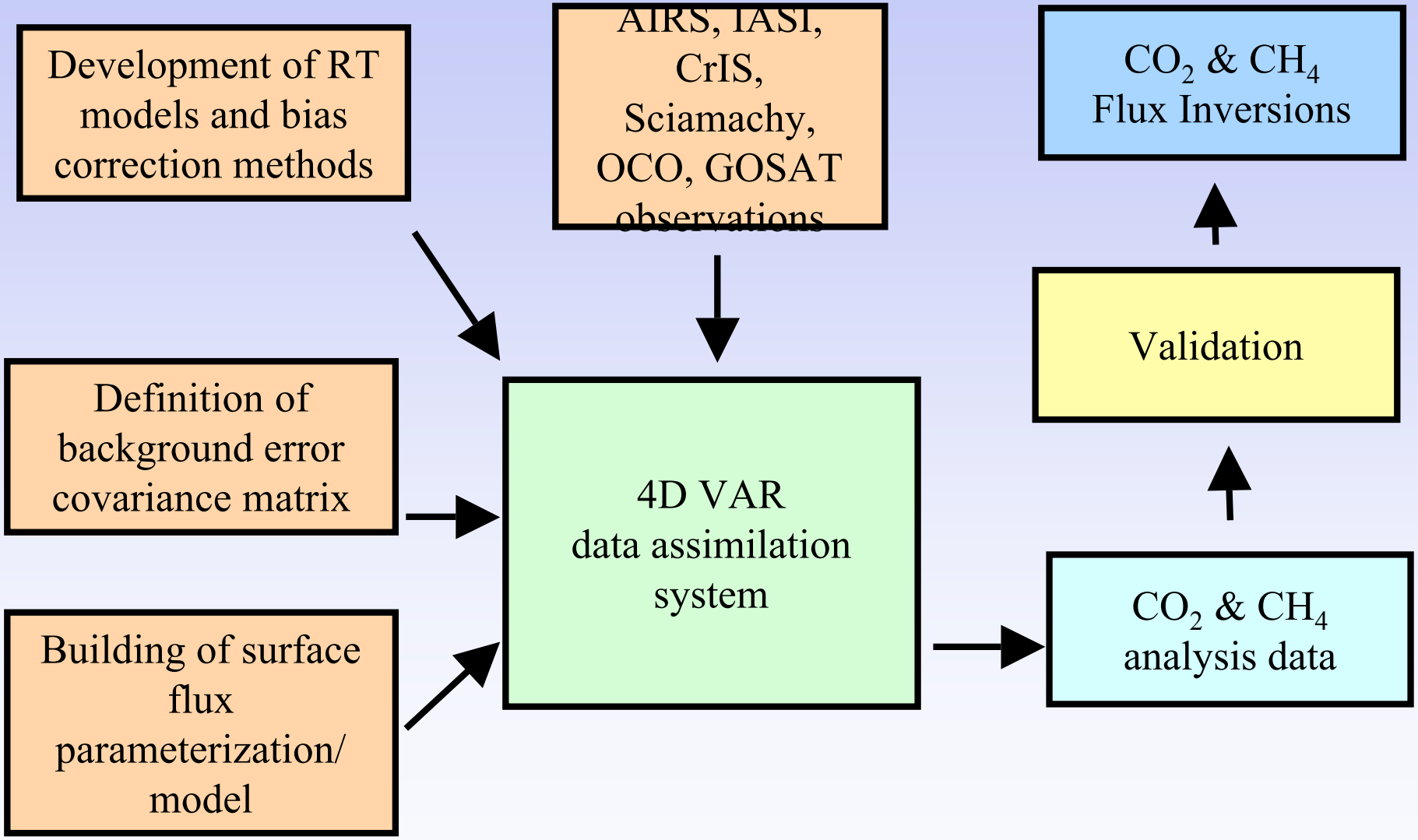
GEMS (**G**lobal and regional **E**arth-system **M**onitoring using **S**atellite and in-situ data) is an European Union funded Integrated Project (IP) within the Sixth Framework Programme.

The project will create a new European operational system for global monitoring of atmospheric chemistry and dynamics and an operational system to produce improved medium-range & short-range air-chemistry forecasts, through much improved exploitation of satellite data.

GEMS organisation

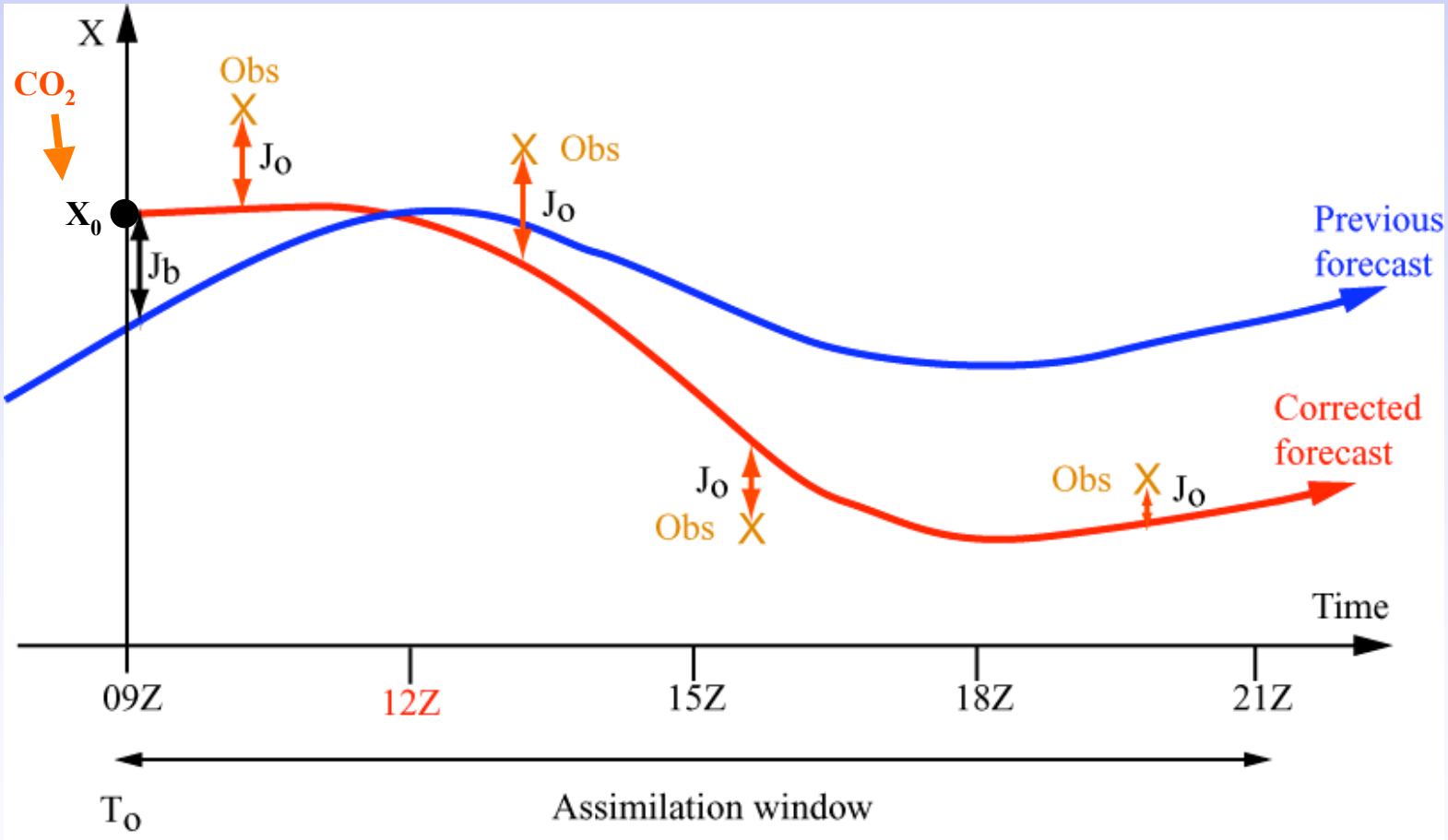


Greenhouse gas activities



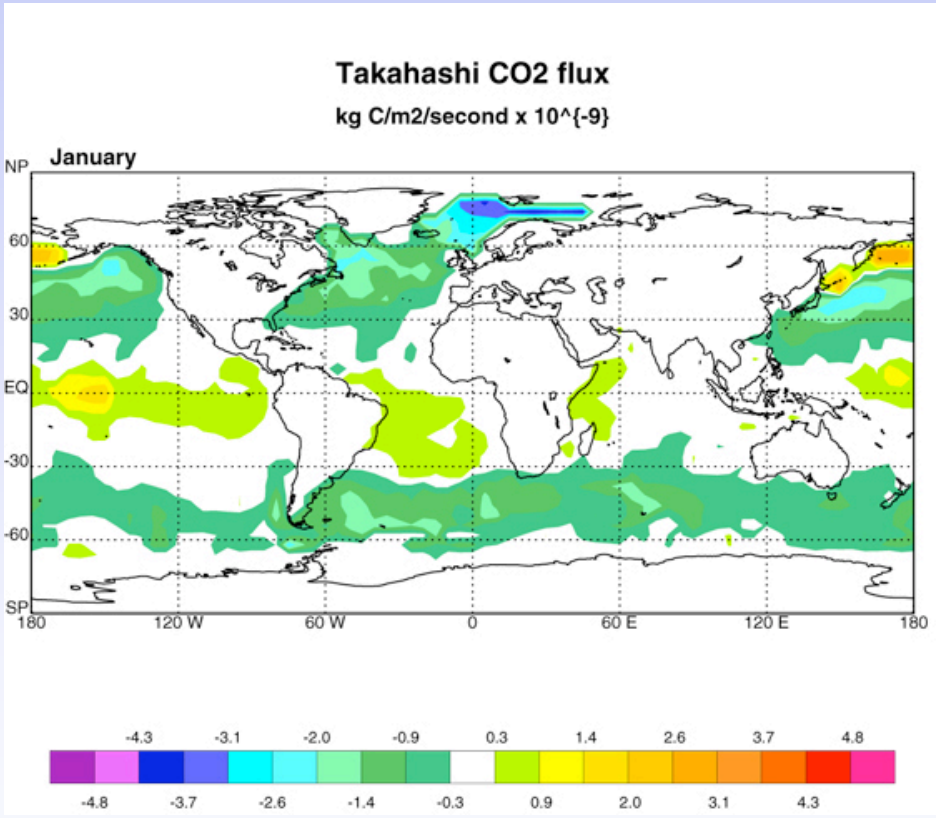
4D-Var Data Assimilation

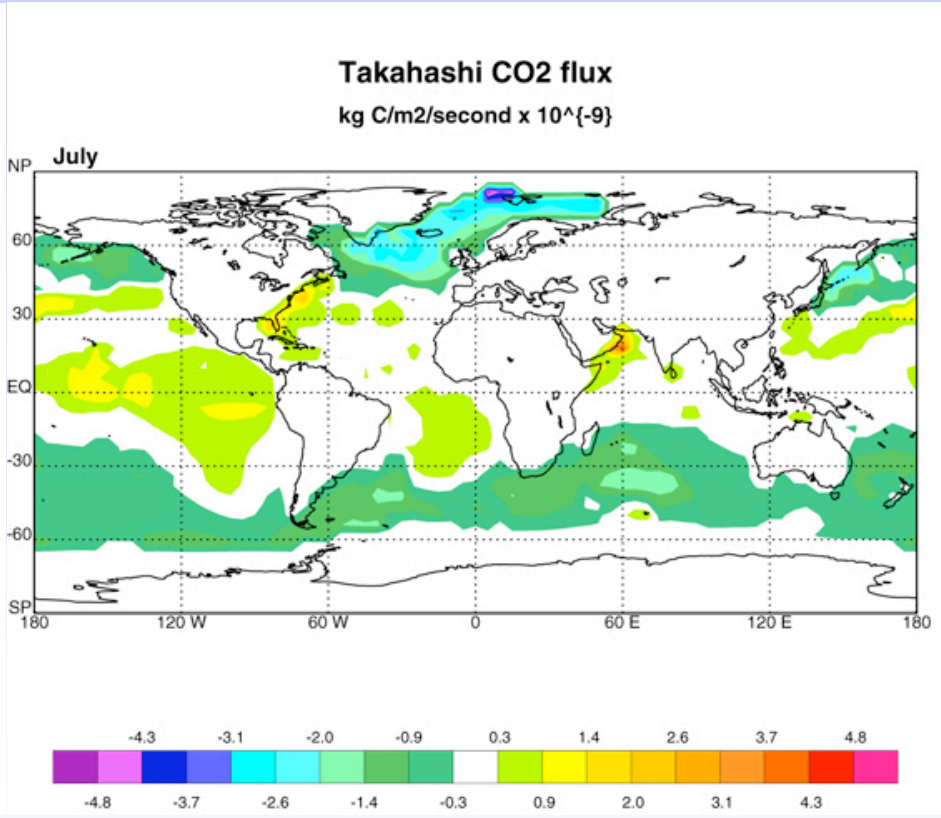
In the 4D-Var version, CO_2 is added to the state vector X_0. This means that only changes to the initial CO_2 field can be made to fit the observations within the assimilation window.



CO_2 surface fluxes - climatology

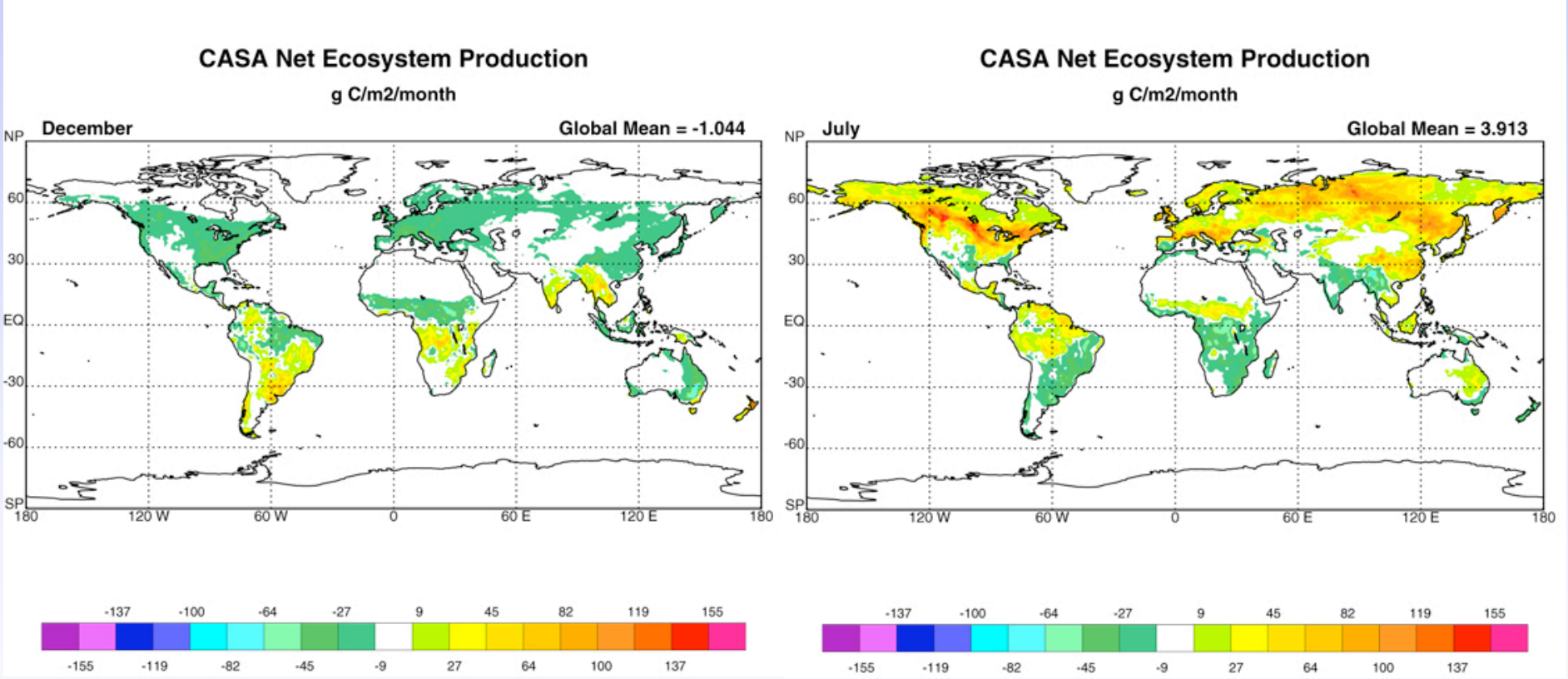
Ocean





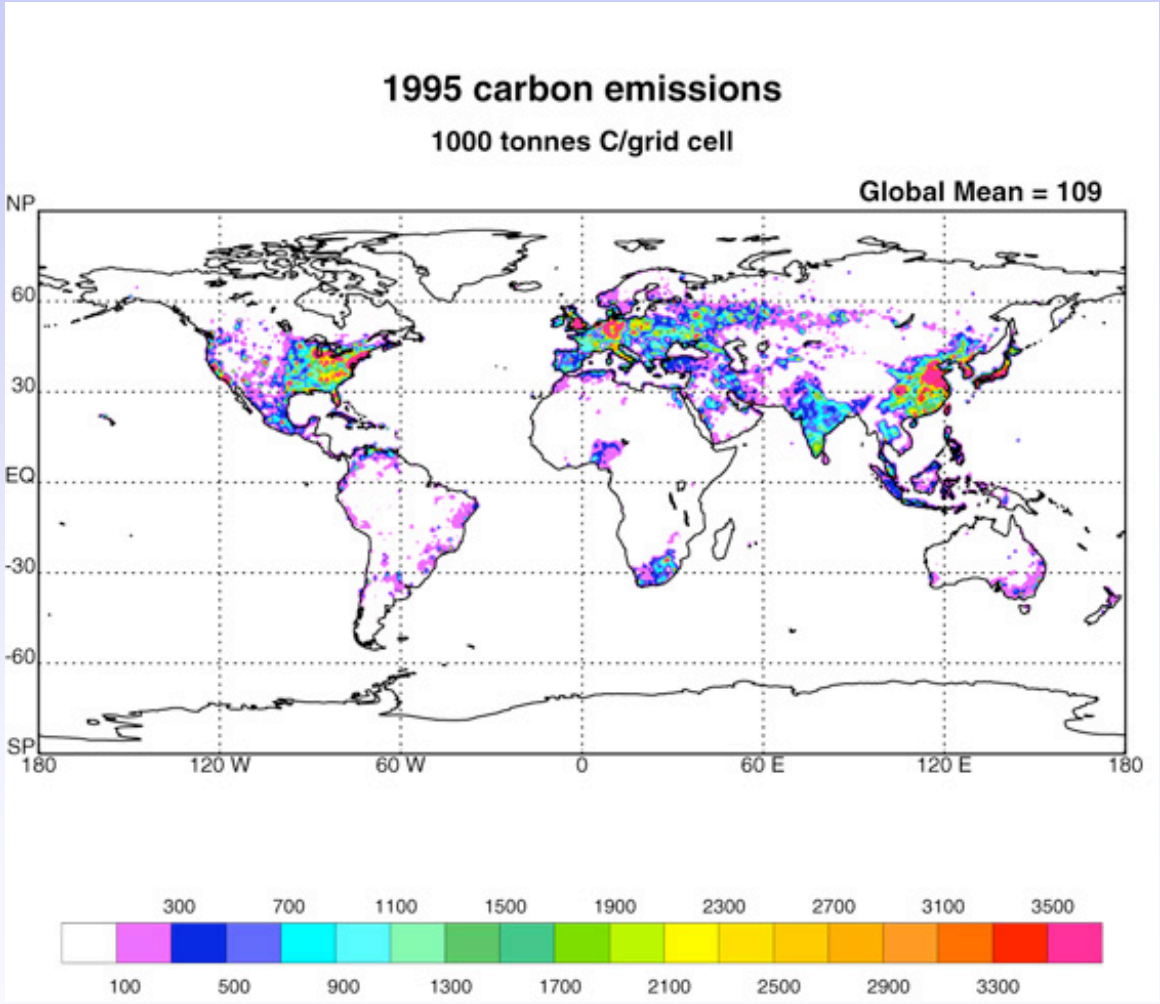
CO_2 surface fluxes - climatology

Natural Biosphere



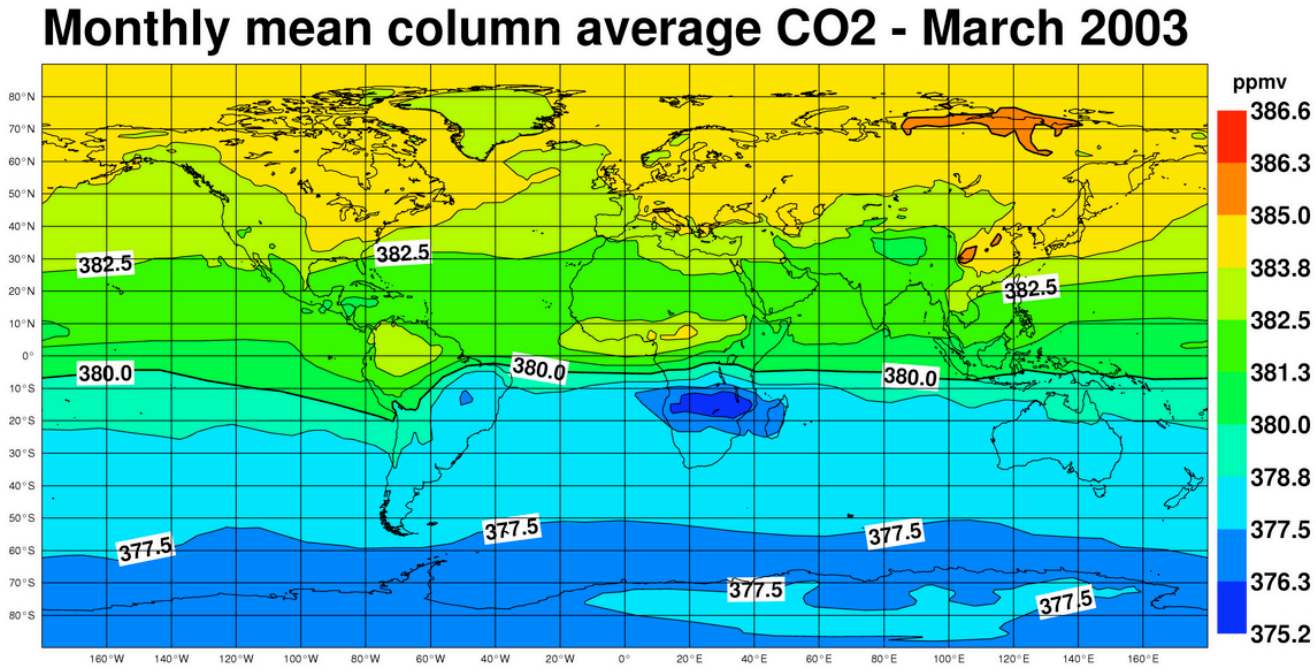
CO_2 surface fluxes - climatology

Anthropogenic



CO_2 in ECMWF forecast model

Using climatological fluxes (CASA, Takahashi, and Andres) we have made a 2 year run to test the system at resolution T159 (~ 1.125˚).



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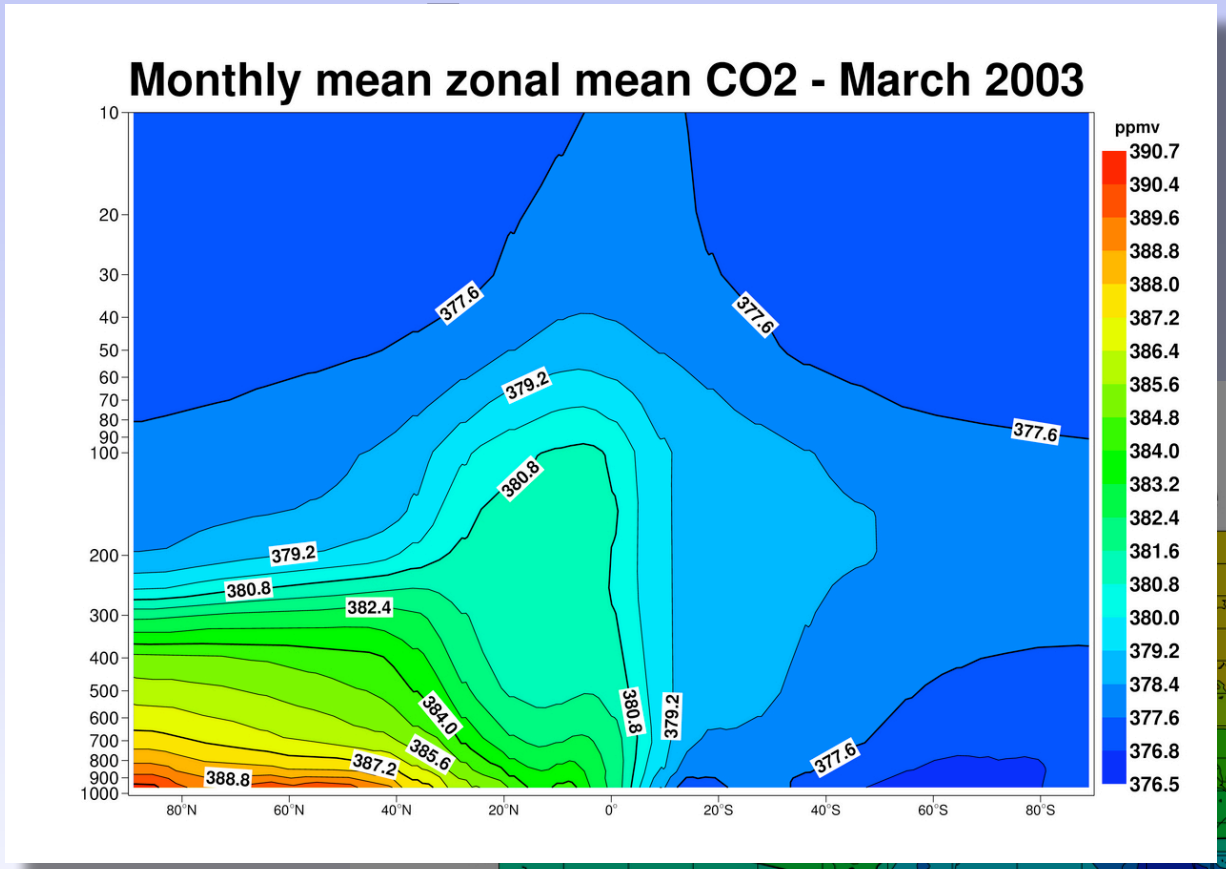
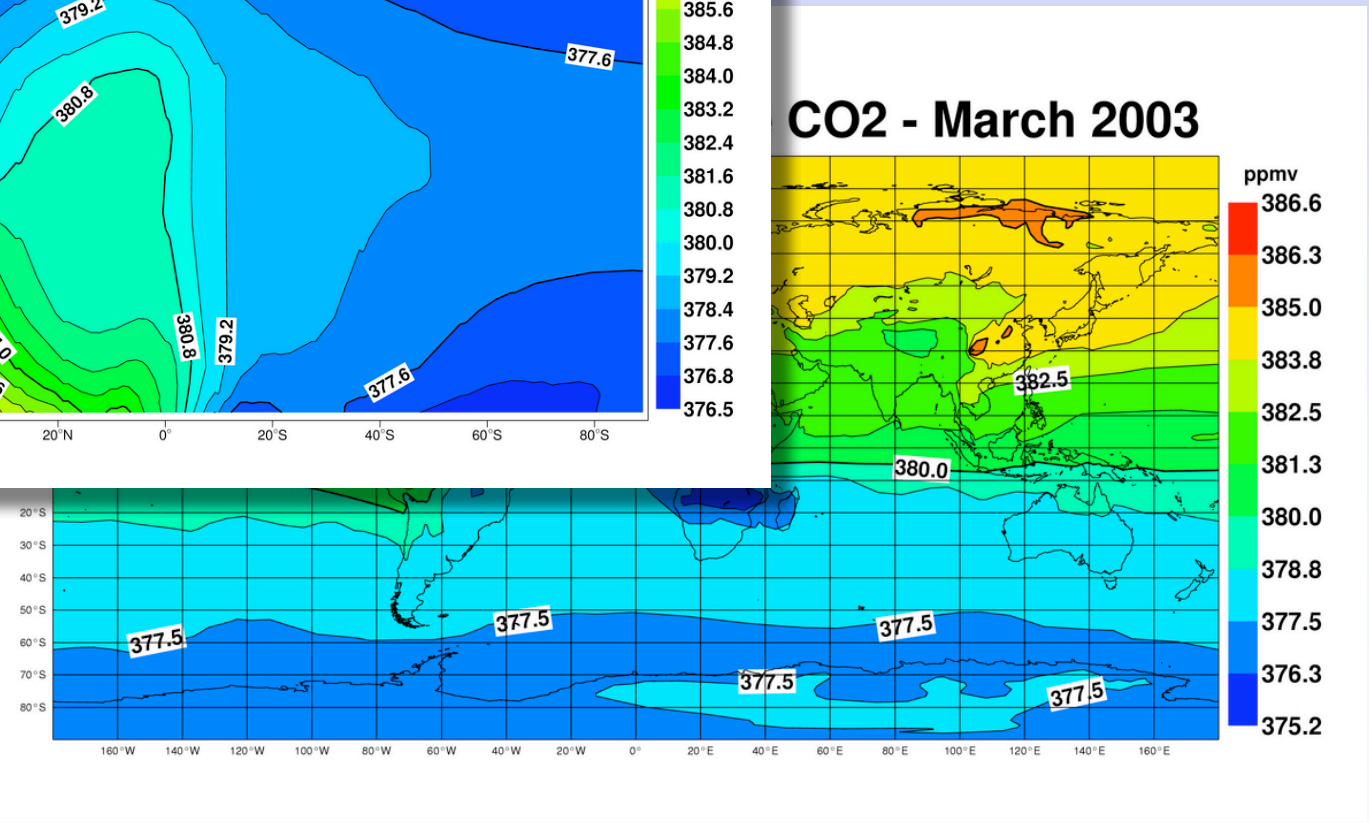
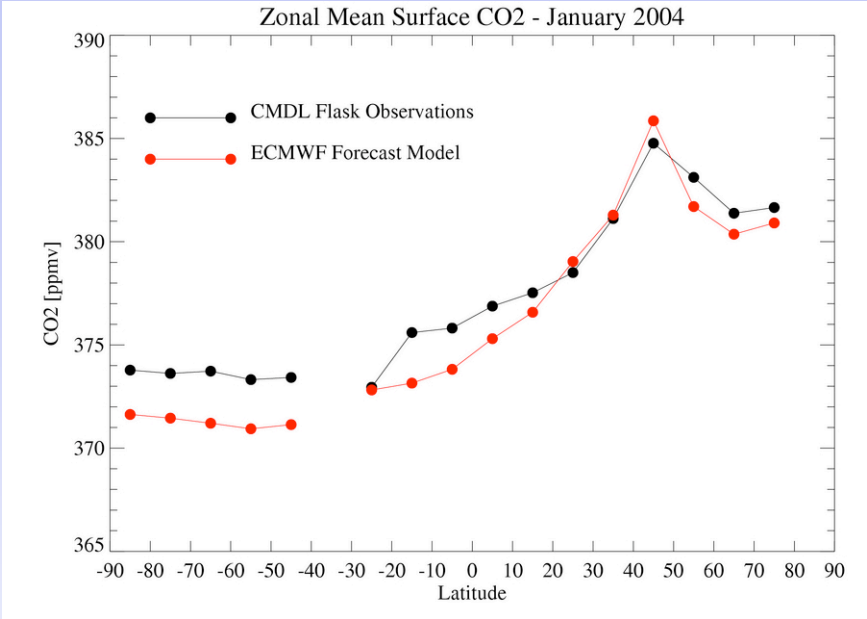
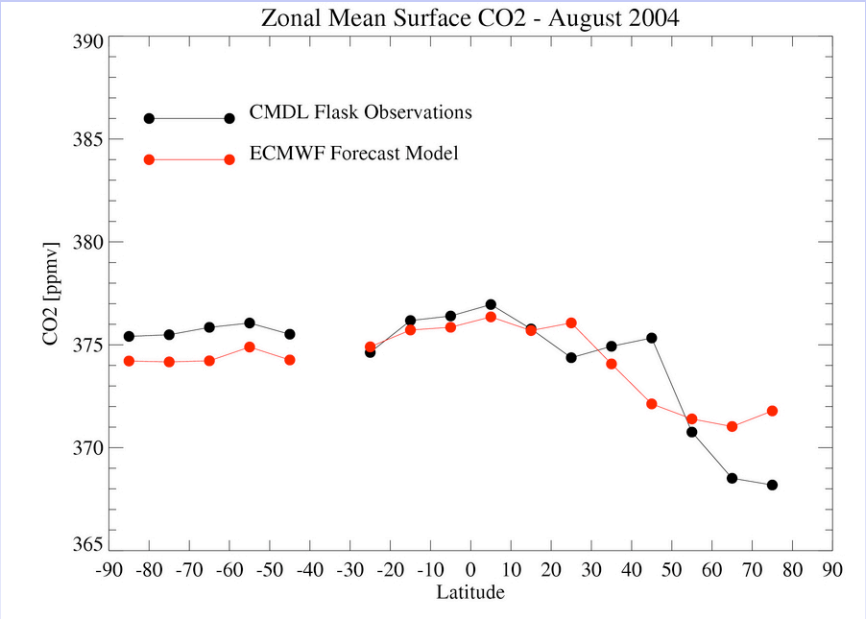




ECMWF model compared to surface flasks

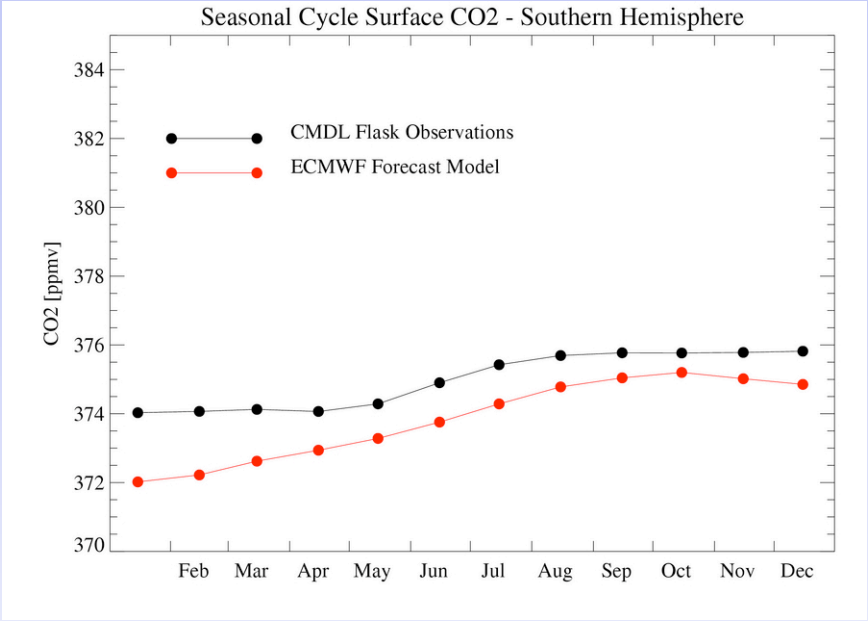


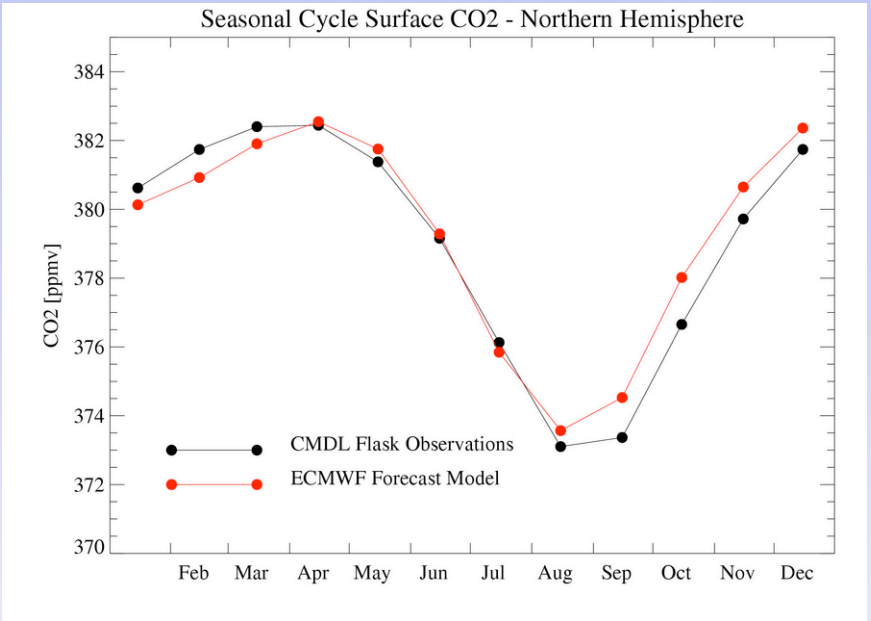


Comparisons between CMDL surface flasks and the free-running ECMWF model show good agreement for the north-south gradients.

Southern hemisphere model values are slightly too low (missing biomass burning??)

ECMWF model compared to surface flasks

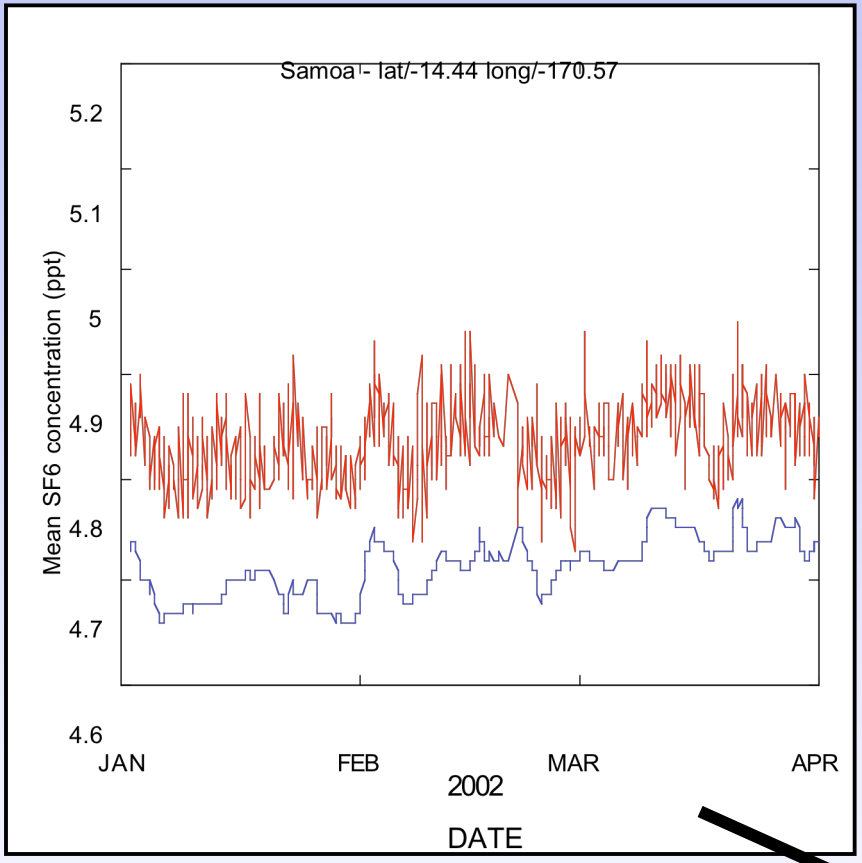




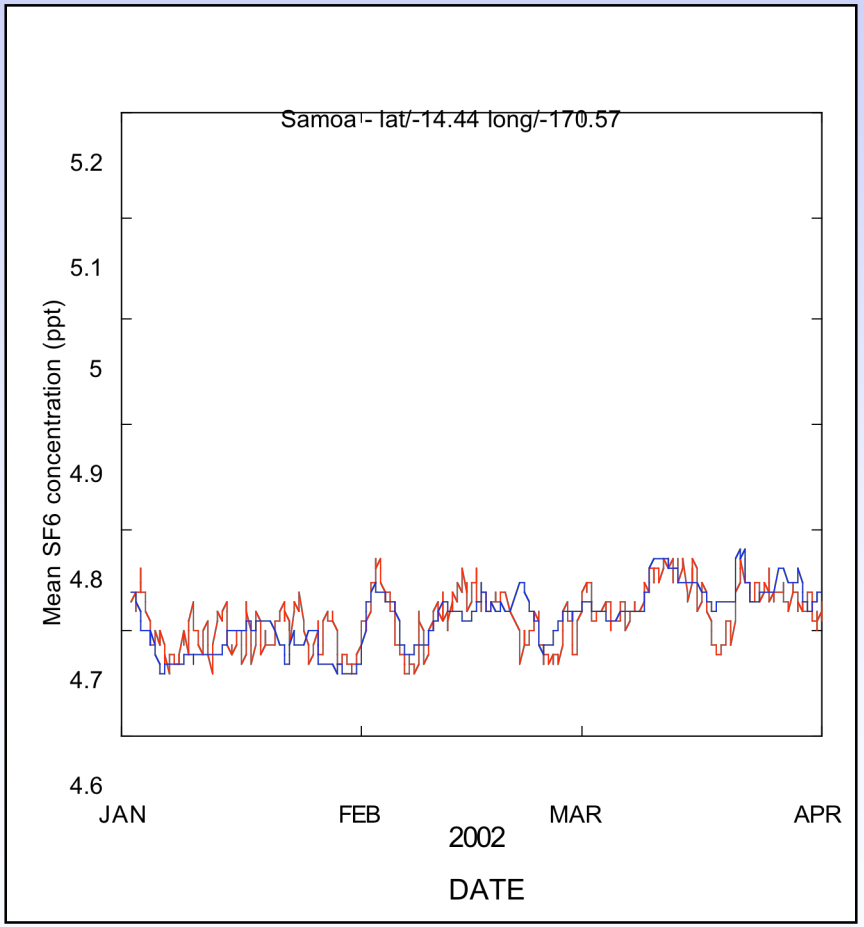
Comparisons between CMDL surface flasks and the free-running ECMWF model show good agreement for the seasonal cycle.

Northern hemisphere summer model values are slightly too high (missing land sink??)

SF_6 high frequency comparisons



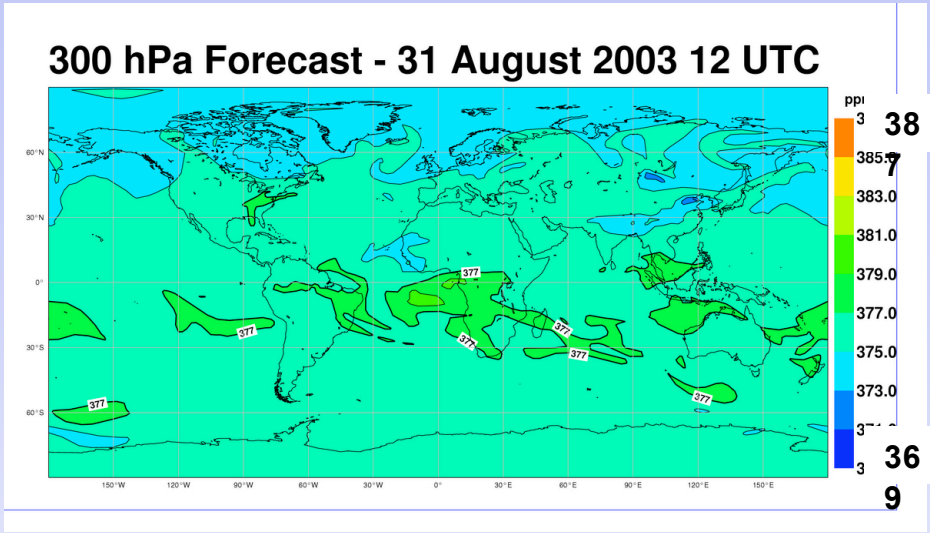
A negative offset and a 15h filtering is applied to observations

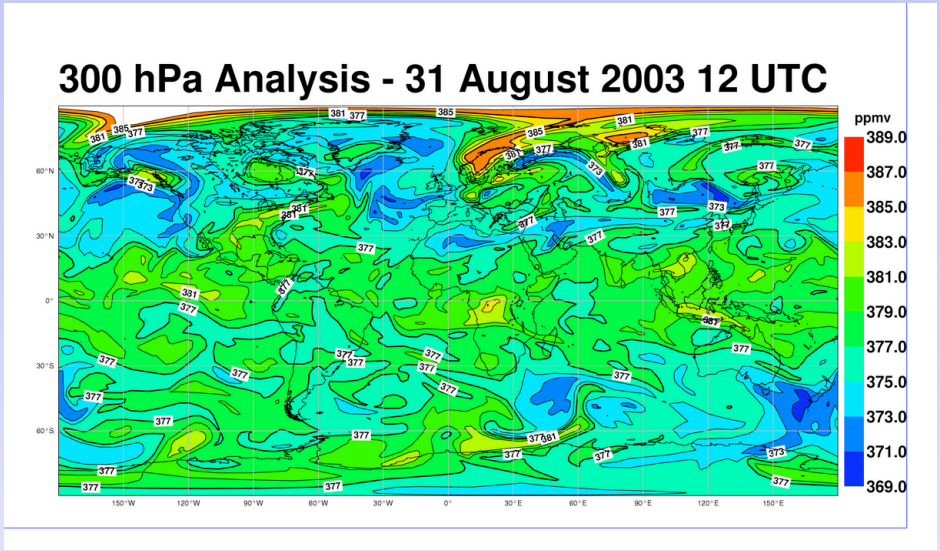


CO_2 4D-Var setup

- T159L60 (1.125˚ x 1.125˚ with 60 levels)
- 6-hour assimilation window
- Background covariance:
  - Each layer only correlated with 2 layers directly above and below
  - Horizontal correlation length of 500 km
  - Standard deviation of 2 ppmv
- Operational AIRS bias correction
- Operational AIRS cloud detection

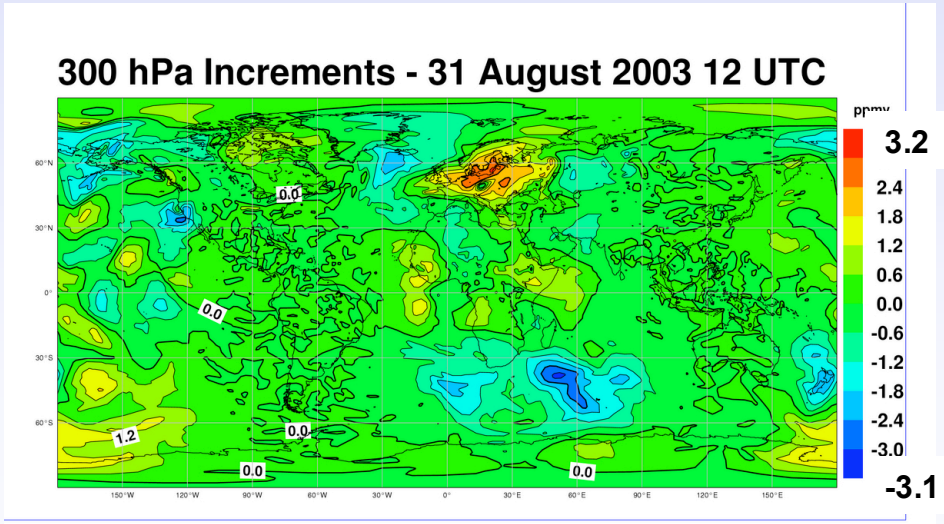
First CO_2 4D-Var analysis results



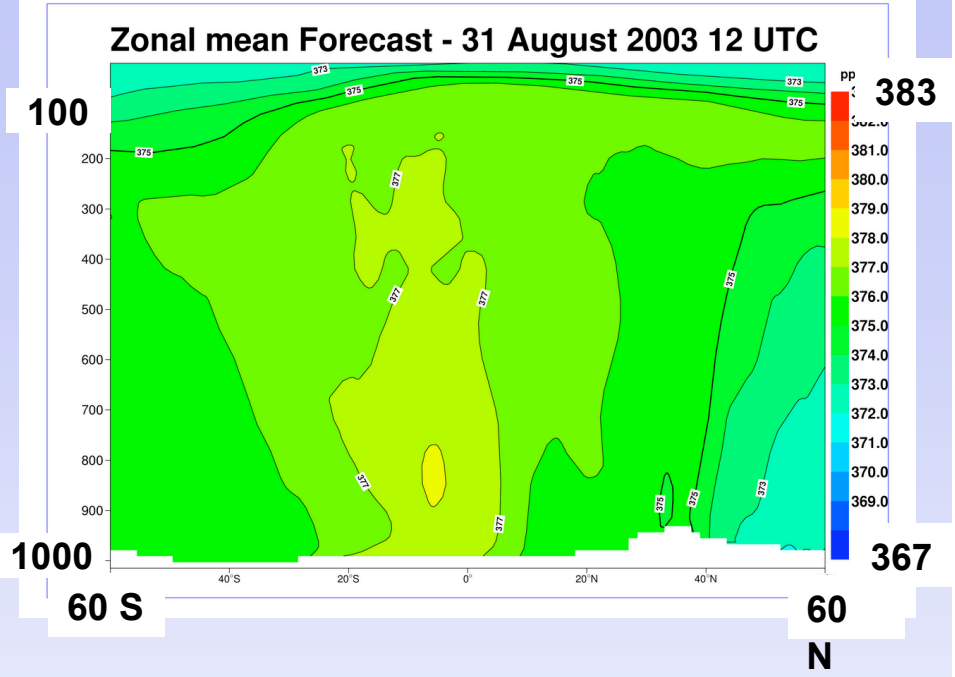


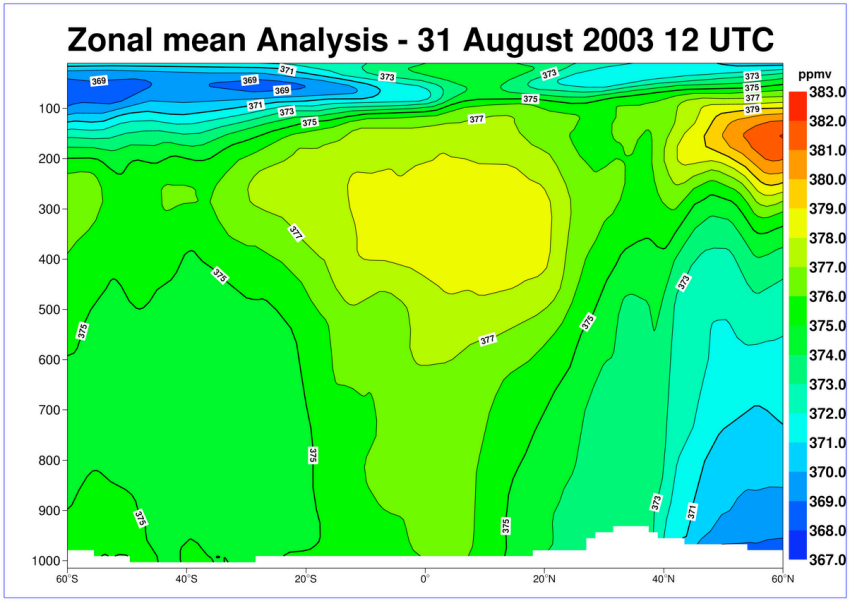
After 31 days of 4D-Var, the analysis has increased the global mean value as well as the spatial gradients.

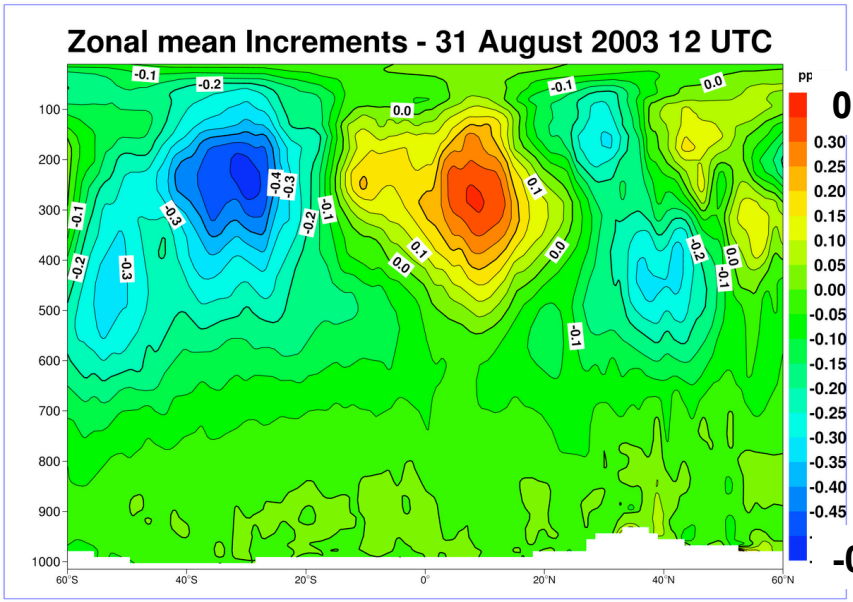
The increments in any analysis cycle are within ± 3 ppmv.



Zonal mean CO_2 distributions





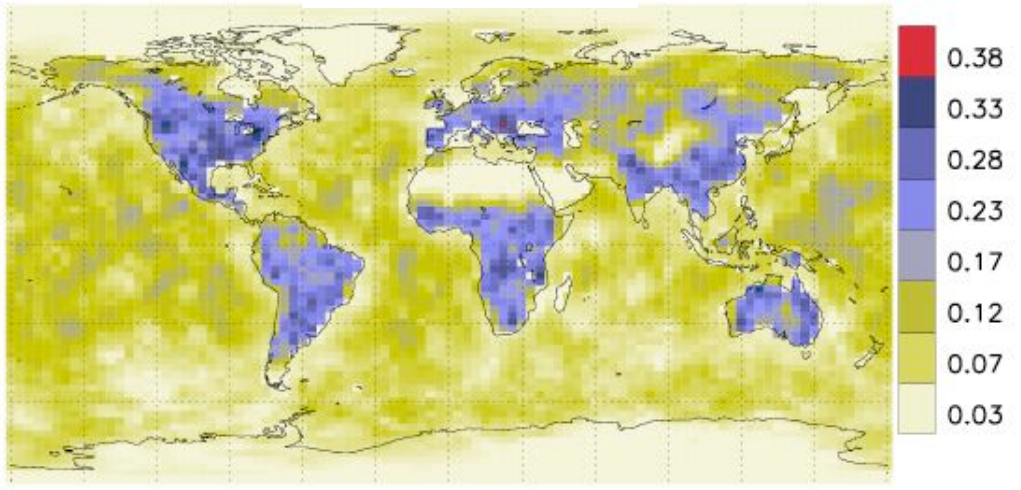


The effect of assimilating AIRS radiances is mainly to increase CO_2 mixing ratios in the upper troposphere and reduce mixing ratios in the SH stratosphere.

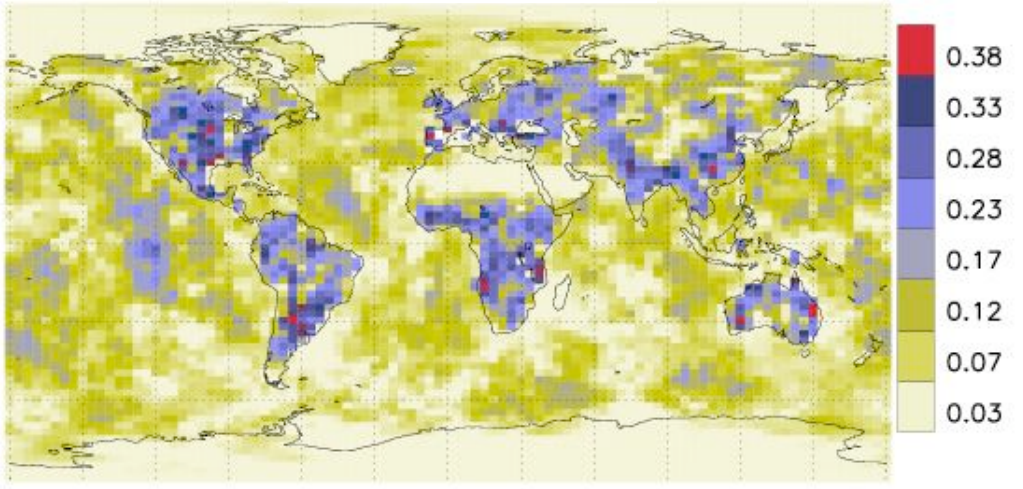
However, a very simple background error matrix was used!!!

CO_2 flux inversions

Weekly fluxes



Monthly fluxes



Simulated flux inversions for OCO data show error reductions between 0 and 20 % over the ocean and between 10 and 40 % over land.

The difference is caused by the small a priori flux errors over ocean compared to the land fluxes.

These estimates assume there are no significant systematic errors.

Thanks to Frédéric Chevallier

Near-future improvements

- Use of diurnal biosphere fluxes
- Possible use of flask optimized fluxes
- Better specification of background covariance matrix
- 12 hour assimilation window
- Different AIRS channel selection
- Use of IASI radiances
- Implement CH_4

Conclusions

- First relatively simple implementation of CO_2 variable in operational data assimilation system proved successful
- Work in progress to build a full 4D-Var greenhouse gas data assimilation system that can combine observations from various satellite sensors to estimate atmospheric CO_2
- These 4D atmospheric fields will then hopefully contribute to a better quantification and understanding of the carbon surface fluxes.